

**REGIONAL HYDROLOGIC MODELING FOR PLANNING THE MANAGEMENT OF  
SOUTH FLORIDA'S WATER RESOURCES THROUGH 2050**

by

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**Summary:**

The natural hydrology of southern Florida has been greatly altered through drainage, canalization, urbanization and agriculture, to the point where the Everglades are now one of the most threatened ecosystems in the nation. In an effort to preserve the remnant Everglades and restore more natural hydrological conditions while maintaining adequate water supply and flood protection, the South Florida Water Management Model was used in the 1999 Central and Southern Florida Comprehensive Review Study (Restudy) to simulate the hydrologic performance of regional water management alternatives.

Proposed water resource management features such as additional surface storage, aquifer storage and recovery, groundwater barriers, and storm water treatment facilities were incorporated into the regional model to simulate management of water resources through 2050. Improved water resource management operations and the removal of structures to increase connectivity of natural areas were also included in the model simulations. Target-based performance measures and hydrological indicators were posted on the internet and used in a multi-agency and public evaluation of the performance of the hydrological modeling prior to the selection of a preferred water resources management alternative. Details of the hydrologic features of the recommended alternative are presented and selected hydrological performance measures are used to highlight its expected performance through 2050.

**Keywords:** Hydrology, modeling, Everglades, water management, planning

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## **A. INTRODUCTION**

Water resources planning and management are critical in south Florida to enhance and restore the natural flow of water to the unique Everglades system, while providing water supply and flood protection to the people of south Florida. The natural hydrology of south Florida has been altered through canalization, urbanization and agriculture to the point where the Everglades original extent (Figure 1a) has been greatly reduced and it has become one of the most threatened ecosystems in the nation (Maltby and Dugan, 1994). The Central and Southern Florida (C&SF) Project forms the backbone of the current south Florida water management system (Figures 1b and 2a) consisting of an extensive system of canals, levees and control structures. Greater than predicted population growth and a better understanding of environmental needs means that the C&SF project now no longer meets the needs of water resource management in south Florida. Hence, Congress authorized a Comprehensive Review Study (Restudy) of the C&SF project to plan for the management of south Florida's water resources through 2050.

The unique hydrology of South Florida due to flat topography, high water tables, sandy soils, and high conductivity of the aquifer system, together with an extensive water control system, makes the southern Florida water management system one of the most complex in the world. Computer simulation models have become the only feasible means to estimate the system-wide impacts of various long-range water management plans in south Florida. The South Florida Water Management Model (SFWMM), developed specifically for the south Florida System was the model utilized in the Restudy to simulate the hydrology of existing and proposed water management alternatives.

This paper describes the regional hydrological modeling that was performed using the SFWMM as part of the Restudy. The Restudy planning process is elaborated, then selected unique model features that were developed as part of the restudy alternatives are described. Performance of the selected alternative is shown using target-based hydrological performance measures.

### **1. Central and Southern Florida (C&SF) Project**

Following a devastating flood in south Florida in 1947, Congress authorized the Central and Southern Florida Project in 1948 for flood control, water conservation, prevention of salt water intrusion and the preservation of fish and wildlife. Construction of the Central and Southern Florida Project formed the greater part of the current south Florida water management system which encompasses 18,000 square miles and consists of over 1800 miles of levees and canals, 200 major water control structures and 27 pump stations. Designed in the 1950s when south Florida had a population of around 500,000 and it was estimated that there might be two million by the year 2000, the C&SF project was successful in achieving its goals and made possible rapid population growth. The system, as it is today, can no longer effectively provide for environmental and water supply needs of the current population of around six million; therefore it requires modification to address needs of the predicted 2050 population of twelve to fifteen million. In 1992, and again in 1996, the United States Congress directed the Army Corps of Engineers to review the Central and Southern Florida Project and determine if it should be changed to restore and preserve south Florida's natural ecosystem while improving water supplies and maintaining flood protection.

## **2. C&SF Project Comprehensive Review Study (Restudy)**

The purpose of the Restudy was to define the major features necessary for ecosystem restoration, water supply and other water resources objectives and outline a process for implementing the plan. In July 1999, the Restudy report was presented to Congress. The Restudy recommends a comprehensive plan with more than 60 major components designed to achieve a balance between ecosystem restoration and urban and agricultural water supply through better water management. The Plan's fundamental goal is to capture most of the fresh water that now flows unused to the Atlantic Ocean and Gulf of Mexico, and to deliver it when and where it is needed most. Approximately eighty percent of this "new water" will be devoted to environmental restoration. The remaining 20 percent will benefit cities and farms, enhancing water supplies and supporting a strong sustainable south Florida.

Economic benefits from the implementation of the Comprehensive Plan are wide ranging. The Plan, often described as the world's largest ecosystem restoration effort, is the result of a six-year collaborative effort by more than 100 scientists and professionals from more than 30 agencies. Once authorized by Congress, the plan will take more than 20 years to construct and will cost an estimated \$7.8 billion. The cost will be shared equally between the federal government and the state of Florida (U.S. Army Corps of Engineers and the South Florida Water Management District, 1999).

## **3. Simulation Models used for the Restudy**

Effective comprehensive water resources planning for managing complex systems like the C&SF Project can only be achieved via simulation models. Three major simulation models were used in the Restudy, the South Florida Water Management Model (SFWMM), the Natural System Model (NSM), and the Across Trophic Level System Simulation (ATLSS) model. The SFWMM simulated the hydrology and water management of the region while the NSM used the same overland and groundwater flow algorithms as the SFWMM to simulate the hydrologic response of the pre-drainage Everglades system. The ATLSS model (The Institute of Environmental Modeling, 1999) was used to provide information on the biological responses of several species to hydrological stressors. The Natural System Model (South Florida Water Management District, 1998) was used in the Restudy primarily as a target for restoring the pre-drainage hydrologic characteristics of the Everglades. The SFWMM (South Florida Water Management District, 1999) is discussed in detail as it pertains to the regional hydrologic modeling undertaken to evaluate different alternative water management plans.

## **4. South Florida Water Management Model (SFWMM)**

The SFWMM is an integrated surface water-groundwater model that simulates the hydrology and management of the south Florida water resources system from Lake Okeechobee to Florida Bay. Major components of the hydrologic cycle including rainfall, evapotranspiration, overland flow, groundwater flow, canal flow, and seepage beneath levees are simulated. Additionally, the model simulates the operations of the C&SF system components including major wellfields in the urbanized east coast, impoundments, canals, pump stations and other water control structures. The ability to simulate key water shortage policies effecting urban, agricultural, and environmental water supplies facilitates the investigation of trade-offs among different use-types

and sub-regions. The model has been calibrated and verified using water level and discharge measurements at hundreds of locations distributed throughout the region within the model boundaries. Documentation (SFWMD, 1997, 1999) including model calibration, verification and peer review are available on the Internet [<http://www.sfwmd.gov/org/pld/hsm/models/sfwmm>].

The model uses a daily time step, consistent with the minimum time increment for which input climatic data (rainfall and evapotranspiration) are available. It can be run for time periods ranging from one month to 31 years with input data for the period from 1965-1995, which includes many drought and wet periods. Rainfall is estimated from more than 600 stations within the model domain and reference crop ET is calculated using climatic data from 12 stations in the Penman-Monteith (Monteith, 1965) method.

A distributed finite difference modeling technique is used to model the gridded portion of the model domain (Figure 2b) which uses a 2-mile by 2-mile square grid over an area of approximately 7000 square miles. Homogeneity of physical and hydrologic characteristics are assumed within each grid cell. The 2-mile discretization in the SFWMM is sufficiently fine to describe the solution to the overland and groundwater flow equations with reasonable resolution and to minimize numerical errors (Lal, 1998). Lumped parameter modeling approaches are used for Lake Okeechobee and the northern lake service areas which include the Caloosahatchee and St. Lucie Basins.

A diffusion wave approximation to the full equations for overland flow is utilized in the gridded portion of the model. Specifically, the components of the cell-to-cell flow are computed using the following expressions:

$$u = 1.49 \frac{h^{\frac{2}{3}}}{n\sqrt{S_n}} \frac{\partial H}{\partial x} \quad (1)$$

$$v = 1.49 \frac{h^{\frac{2}{3}}}{n\sqrt{S_n}} \frac{\partial H}{\partial y} \quad (2)$$

Where  $u$  and  $v$  are the velocity components in the  $x$  and  $y$  directions, respectively. Other variables defined:  $n$  is the overland flow roughness coefficient that depends on the depth of flow;  $S_n$  is the energy grade line slope; and  $H$  is the water level above a given datum. An Alternating Direction Explicit (ADE) scheme with four six-hour time slices is utilized to solve for the overland flow from one cell to another.

Groundwater flow is solved using the vertically-averaged, transient groundwater flow equation:

$$\frac{\partial}{\partial x} \left( T_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( T_{yy} \frac{\partial h}{\partial y} \right) = S \frac{\partial h}{\partial t} - R \quad (3)$$

Where  $T$  is transmissivity,  $S$  is storage coefficient, and  $R$  is recharge to the groundwater table. The model utilizes a variation of the Saul'yev (1964) method to solve the above equation. This technique is unconditionally stable and explicit. To minimize bias, the numerical formulation is solved in four different directions in four successive time steps. Highly concentrated groundwater flow beneath levees cannot be simulated with a 2 mile x 2 mile scale model,

therefore separate regression equations, based on more detailed 2-dimensional finite element modeling, were developed to simulate localized levee under-seepage (SFWMD, 1999).

Over 1,400 miles of levees and canals, 18 major pump stations, and more than 180 water control structures are simulated in the model. For most canals in the system, the SFWMM utilizes a mass balance approach to account for changes of storage in the canal due to inflows and outflows. An iteration scheme solves for the equilibrium canal stage each time step. This approach produces satisfactory results for daily time steps. For the primary canals in the Everglades Agricultural Area (Figures 1b and 2a) that are intensively managed via pumps, the SFWMM uses a backwater profile solution scheme each time step.

The preponderance of the SFWMM code is dedicated to mimicking the complex operational rules which regulate flow into and out of canals and water storage areas. Current or proposed policies and rules for flood control, water supply, and environmental restoration/enhancement can be simulated by the SFWMM.

## **B. PLANNING PROCESS**

An iterative process (Figure 3) was used to plan the management of South Florida's water resources in the Restudy. After initial screening, formulation of the baseline conditions, and definition of performance measures, each of the several alternative plans that were modeled went through the process of: alternative formulation, alternative design, regional scale modeling, publishing of results on the internet, and evaluation, before the next alternative was formulated. This process fostered a very open exchange of ideas permitting feedback from a wide variety of agencies and the public on each alternative prior to formulation of the next alternative. It also meant that lessons learned in early alternatives could be used to build better water management features into subsequent alternatives.

Initial screening involved using three different models namely the Everglades Screening Model, the Object-enhanced Screening Model, and the SFWMM. Screening was undertaken primarily to evaluate the potential of individual components to understand how each component performed, before building the components into the SFWMM and modeling them together with existing components. Results from the initial screening were used to guide the alternative plan development process.

Alternative plan formulation was undertaken by an inter-agency, inter-disciplinary team. Initially the baseline conditions, against which all future alternatives would be compared, were defined. Two base conditions were defined: a current system condition and a future without-project condition. The current condition was defined to represent current infrastructure and operations with 1995 land use and water demands. The future without-project condition was defined to represent 2050 land use and water demands with water management features from projects other than the Restudy that are expected to be complete by 2050. In this paper the future without project condition is not presented. Instead, the current condition is compared with the future condition that would likely result with the components from the selected Restudy alternative.

An important part of the planning process was to define performance measures against which the performance of simulated alternatives could be evaluated. Conceptual models were used to develop socio-economic and ecological targets and performance measures, which were then transformed into hydrological performance measures and used to compare different model simulations. The primary ecological objectives were to increase the total (or functional) spatial extent of natural areas, improve habitat quality and improve native plant and animal abundance and diversity. Hydrologic measures of performance included uninterrupted hydroperiods, surface and groundwater depth patterns, estuarine flow volumes, seasonal timing and distribution patterns and connectivity. The Natural System Model, which provides an estimate of the pre-drainage system response to the same climatic record used by the SFWMM, was used as the basis for determining these targets, unless better scientific information was available. Social objectives included increasing the availability of fresh water supply for agriculture, municipal and industrial purposes, reducing flood damages, and providing recreational and navigational opportunities.

Once the goals of an alternative had been formulated in concept, an Alternative Design Team (ADT) developed components for the alternative that would produce the desired effect. The design team worked very closely with the regional-scale modelers to provide component details such as structure capacities and desired operation. Often there were iterations between the modelers and designers when the design of a component needed to be modified following preliminary model runs of each alternative.

After each alternative was simulated and performance measures for the alternative generated, results were posted on an Internet web site [<http://www.sfwmd.gov/org/pld/restudy/hpm>]. There were in excess of 900 tables and graphics for each set of alternative comparisons made, which meant that the internet was a very efficient means to share this information with a large audience. Animation of flow simulations could also be viewed on the web site. A feature of the web site (Figure 4) that was useful for the study team and the public was the ability to evaluate the alternatives on-line and submit the evaluation electronically.

Formal evaluation of the alternatives was conducted by the Alternatives Evaluation Team (AET). The AET made use of the electronically submitted evaluations, together with their own evaluations and those submitted by mail, to evaluate the performance of each alternative and provide direction to the ADT on where performance of an alternative could be improved. This performance-based evaluation method helped focus the evaluator's attention on identifying where the alternative plans did not meet prescribed targets and goals. AET feedback was used by the ADT in developing the subsequent alternatives. The AET also ranked the final alternative plans and selected a preferred alternative.

## **C. ALTERNATIVE PLAN COMPONENTS**

Through the Restudy planning process more than 60 plan components were designed. Sets of these components were strategically assembled to form 6 alternative plans that were modeled using the SFWMM. In this section, nine of the larger and/or more unique components of the recommended Restudy plan are described. Following each of these selected component descriptions is a discussion of how the components were built into the SFWMM.

The selected structural components included several types: above-ground storage, in-ground storage, groundwater management and environmental enhancement.

A number of water storage facilities are planned north of Lake Okeechobee, in the Caloosahatchee and St. Lucie basins, in the Everglades Agricultural Area, and in Palm Beach, Broward and Miami-Dade counties. These areas will encompass approximately 181,300 acres and will have the capacity to store 1.5 million acre-feet of water.

The groundwater management components address the millions of gallons of groundwater lost each year as it seeps away from the Everglades towards the east coast. Groundwater flows from the Everglades to the Lower East Coast developed areas into adjacent canals (levee underseepage), or recharges the surficial aquifer. Much of the wet season groundwater flow from the Everglades is captured by the drainage canals and discharged to tide. The plan includes features to reduce unwanted water loss and redirect this flow westward to the Water Conservation Areas, Everglades National Park, and northeast Shark River Slough. The three features to reduce seepage are: (1) adding impervious barriers to the levees to block the loss of water; (2) installing pumps near levees to redirect water back into the Everglades; and (3) holding water levels higher in undeveloped areas between the Everglades and Palm Beach, Broward and Miami-Dade counties.

The operational components involve changes in water delivery schedules in some areas to alleviate extreme fluctuations. Lake Okeechobee water levels will be modified to improve the Lake health. In other areas, rainfall-driven operational plans will enhance the timing water flows.

Each of the selected components listed below is described in moderate detail, followed by a brief description of how the component was built into the SFWMM.

### Selected Structural Components

1. Everglades Agricultural Area Storage
2. North of Lake Okeechobee Storage
3. Water Preserve Areas
4. Lake Belt Storage Areas
5. Aquifer Storage and Recovery
6. Water Conservation Areas 3A and 3B Levee Seepage Management
7. Decompartmentalization

### Selected Operational Components

8. Lake Okeechobee Regulation Schedule
9. Rainfall Driven Operations

## **1. Everglades Agricultural Area Storage**

This component includes above-ground reservoir(s) with a total storage capacity of approximately 360,000 acre-feet located in the Everglades Agricultural (Figures 1b and 2a) and conveyance capacity increases for the Miami, North New River, and Bolles and Cross Canals. The initial design for the reservoir(s) assumed 60,000 acres, divided into three, equally sized compartments (1, 2, and 3), with the water level fluctuating up to 6 feet above grade in each compartment. The final size, depth and configuration of this facility will be determined through more detailed planning and design.

The purpose of this feature is to improve the timing of environmental deliveries to the Water Conservation Areas, including reducing damaging flood releases from the Everglades Agricultural Area to the Water Conservation Areas, reducing Lake Okeechobee regulatory releases to the estuaries, meeting Everglades Agricultural Area irrigation and Everglades water demands, and increasing flood protection in the Everglades Agricultural Area.

Runoff from the Everglades Agricultural Area, Miami and North New River Canal Basins and regulatory releases from Lake Okeechobee will be pumped into the reservoirs. Compartment 1 discharges will be used to meet Everglades Agricultural Area irrigation demands only. Compartment 2 discharges will be used to meet environmental demands as a priority and can be used to supply a portion of agricultural demands if the environmental demands equal zero. Compartment 3 discharges will be used to meet environmental demands. The storage compartments can also be designed to provide a water quality treatment function, augmenting the performance of the Everglades Construction Project (SFWMD or Burns and McDonnell, 1994) and ensuring protection of water quality in the Everglades Protection Area. Design of this feature for water quality performance will be based on water quality targets for the Everglades Construction Project and other water quality targets developed to protect designated uses in Everglades Agricultural Area waters.

In the SFWMM each compartment of the EAA reservoir is modeled as an above groundwater holding facility with vertical walls and is identified by a hydrologic basin number that is assigned to appropriate grid cells. Thus, no overland flow occurs from one compartment of the EAA reservoir to another. However, spillover occurs from compartment 1 and 2, and/or from compartment 2 to compartment 3 when storage in the compartment approach the maximum. Localized seepage losses from the EAA Reservoir are not simulated which is consistent with the proposed intent of pumping the seepage losses back into the reservoir.

The model accounts for differences in the actual area of each compartment and the area represented by the grid system, i.e., multiples of four square miles. Since rainfall and evapotranspiration depths are assumed to occur uniformly for each grid cell, their effect on reservoir stage is transformed by a proportionality factor relating compartment area and the area of the grid cells(s) where the compartment(s) are located. This equivalent reservoir compartment stage is used in determining available storage in each compartment and is also the basis for calculating discharges through inlet and outlet structures.

## **2. North of Lake Okeechobee Storage Reservoir**

This component includes an above-ground reservoir and a 2,500-acre stormwater treatment area. The total storage capacity of the reservoir is approximately 200,000 acre-feet and is located in the Kissimmee River Region, north of Lake Okeechobee. The specific location of this facility has not been identified; however, it is anticipated that the facility will be located in Glades, Highlands, or Okeechobee Counties. The initial design of this feature assumed a 20,000-acre facility (17,500-acre reservoir and 2,500-acre treatment area) with water levels in the reservoir fluctuating up to 11.5 feet above grade. The final size, depth and configuration of this facility will be determined through more detailed planning, land suitability analyses, and design. Future detailed planning and design activities will also include an evaluation of degraded waterbodies within the watersheds of the storage/treatment facility to determine appropriate pollution load reduction targets, and other water quality restoration targets for the watershed.

The purpose of this facility is to detain water during wet periods for later use during dry periods and reduce nutrient loads flowing to the lower Kissimmee River and Lake Okeechobee. This increased storage capacity will reduce the duration and frequency of both high and low water levels in Lake Okeechobee that are stressful to the Lake's littoral ecosystems, and cause large discharges from the Lake that are damaging to the downstream estuary ecosystems. Depending upon the proposed location(s) of this water storage/treatment facility and pollutant loading conditions in the watershed(s), the facility could be designed to achieve significant water quality improvements, consistent with appropriate pollution load reduction targets.

The operation of this component assumes that water from Lake Okeechobee, the Kissimmee River or other contributing drainage basins will be pumped into the storage reservoir/stormwater treatment area when the Lake water levels are forecasted to rise significantly above desirable levels for the Lake littoral zone. Water held in the reservoir and stormwater treatment area will not be released until the lake levels decline to ecologically acceptable levels.

Unlike the EAA reservoir, the north of Lake Okeechobee Storage Reservoir is not located within the grid network of SFWMM. Thus the reservoir is treated as a lumped system. The total storage capacity of the reservoir in SFWMM is 200,000 acre-ft, comprising of a 20,000 acre reservoir with a maximum depth of 11.5 feet above grade. The reservoir is assumed to have a flat bottom. The storage in the reservoir is determined for each time-step (1 day) via a mass balance procedure which accounts for all major hydrologic fluxes.

For modeling purposes excess water is always pumped into the reservoir directly from Lake Okeechobee. Similarly, when Lake Okeechobee stages are sufficiently low or forecasted to be sufficiently low in the next six months, water is retrieved directly from the reservoir into Lake Okeechobee, assuming the water is sufficiently treated by the proposed 2,500 acre stormwater treatment area.

### **3. Water Preserve Areas**

The Water Preserve Areas concept is designed to capture and store excess surface waters that are normally released to tide via the C&SF Project canal system by back-pumping these surface waters to the buffer/storage areas east of the protective levee referred to as Water Preserve Areas. The system benefits associated with the Water Preserve Areas may include; 1) preventing over-drainage of the Everglades and re-establishing natural hydropatterns within existing natural areas; 2) provide for the re-creation of natural storage systems lost due to the impacts of development; 3) provide for increased spatial extent of short hydroperiod wetlands; 4) provide a buffer between the Everglades and the increasingly urbanized lower east coast area; and, 5) provide for improved water supply to the lower east coast.

Numerous alternatives for the Water Preserve Areas were investigated ranging from a continuous Everglades buffer consisting of an interconnected system of marshlands (as proposed by the National Audubon Society) to small individual "cells" that were combined to form wetland areas, reservoirs and aquifer recharge basins. The Water Preserve Areas are located in Palm Beach County, Broward County and Dade County and are shown in Figure 5.

Ongoing finer-scale analysis will identify the functions the Water Preserve Areas should provide in order to optimize system-wide benefits. Upon completion of alternative screening efforts, detailed engineering analysis and refinement of the WPAs alternatives will be accomplished. The detailed engineering analysis will optimize structural and operational design of the WPAs essential to restoration of the Everglades and Florida Bay ecosystems while providing for other water-related needs to include water supply and water quality. The detailed engineering analysis will evaluate the size, location and operational aspects of the Water Preserve Areas necessary to provide for the optimization of the multi-purpose nature of these areas. Other water-related needs and issues which will be addressed in the detailed engineering design of the WPAs include: water supply/use, water quality, seepage management, aquifer storage and recovery, salt water intrusion, estuarine system needs, urban development impacts and the presence of exotics in the proposed WPAs.

The Water Preserve Areas are simulated in the SFWMM as leveed above-ground reservoirs. If applicable, localized Everglades seepage losses from under the protective levees are collected in the Water Preserve Area. Any localized seepage losses under the levees of the Water Preserve Areas are assumed to be pumped back into the Water Preserve Areas.

### **4. Lake Belt Storage Areas**

Two rock mining areas in Miami-Dade County will be converted to in-ground storage areas. The need for two large in-ground storage reservoirs, North Lake Belt Storage and Central Lake Belt Storage Area (Figure 6), in such close proximity is due to the differences in the quality of the water each storage area receives. While North Lake Belt Storage Area receives stormwater runoff from urban and low density agriculture land uses, the Central Lake Belt Storage Areas receives deliveries from Water Conservation Areas 2B, 3A and 3B when water levels exceed environmentally desired target elevations.

#### *North Lake Belt Storage Area*

This component includes canals, pumps, water control structures, and an in-ground storage reservoir with a total capacity of approximately 90,000 acre-feet located in Miami-Dade County. The initial design of the reservoir assumed 4,500 acres with the water level fluctuating from ground level to 20 feet below grade. A subterranean seepage barrier will be constructed around the perimeter to enable drawdown during dry periods, to prevent seepage losses, and to prevent water quality impact due to the high transmissivity of the Biscayne Aquifer in the area.

The reservoir will be located within an area proposed for rock mining. A pilot test of this component will be conducted prior to final design to determine construction technologies, storage efficiencies, impacts upon local hydrology, and water quality effects. The water quality assessment will include a determination as to whether the in-ground reservoir with perimeter seepage barrier will allow storage of untreated runoff without concerns of groundwater contamination. The final size, depth and configuration of these facilities will be determined through more detailed planning and design to be completed as a part of the ongoing Water Preserve Areas Feasibility Study and will address appropriate pollution load reduction targets necessary to protect the adjacent surficial aquifer and downstream receiving surface waters.

The purpose of this feature is to capture and store a portion of the stormwater runoff from the C-6, western C-11 and C-9 Basins. The stored water will be used to maintain stages during the dry season in the C-9, C-6, C-7, C-4 and C-2 Canals and to provide water deliveries to Biscayne Bay to aid in meeting salinity targets. Runoff is pumped and gravity fed into the in-ground reservoir from the C-6 (west of Florida's Turnpike), western C-11, and C-9 Basins. Outflows from the facility will be directed into the C-9 Stormwater Treatment Area/Impoundment or other smaller treatment areas surrounding the facility for treatment prior to delivery to the C-9, C-7, C-6, C-4 and C-2 Canals. If necessary, additional stormwater treatment areas will be incorporated into the design.

#### *Central Lake Belt Storage Area*

This component includes pumps, water control structures, a stormwater treatment area, and a combination above-ground and in-ground storage reservoir with a total storage capacity of approximately 190,000 acre-feet located in Miami-Dade County. The initial design of the reservoir assumed 5,200 acres with the water level fluctuating from 16 feet above grade to 20 feet below grade. A subterranean seepage barrier will be constructed around the perimeter to enable drawdown during dry periods and to prevent seepage losses.

A pilot test of this technology will be conducted prior to final design of this component to determine construction technologies, storage efficiencies, impacts upon local hydrology, and water quality effects. Since this facility is to be located within the protection area of Miami-Dade County's Northwest Wellfield, the pilot test will also be designed to identify and address potential impacts to the County's wellfield which may occur during construction and/or operation. The stormwater treatment area was assumed to be 640 acres with the water level fluctuating up to 4 feet above grade. The final size, depth and configuration of these facilities will be determined through more detailed planning and design to be completed as a part of the Water Preserve Areas Feasibility Study.

The purpose of the feature is to store excess water from Water Conservation Areas 2 and 3 and provide environmental water supply deliveries to: (1) Northeast Shark River Slough, (2) Water Conservation Area 3B, and (3) to Biscayne Bay, in that order, if available. Due to the source of the water (Water Conservation Areas 2 and 3), it is assumed that water stored in this facility is of adequate quality to return to the Everglades Protection Area

Excess water from Water Conservation Areas 2 and 3 will be diverted into the borrow canals east of the protective levee, which run along the eastern boundaries of the Water Conservation Areas, and pumped into the Central Lake Belt Storage Area. Water supply deliveries will be pumped through a stormwater treatment area prior to discharge to the Everglades via the borrow canals. If available, deliveries will be directed to Biscayne Bay through the Snapper Creek Canal at Florida's Turnpike. A structure will be provided on the Snapper Creek Canal to provide regional system deliveries when water from the Central Lake Belt Storage Area is not available.

Unlike the EAA reservoir or north of Lake Okeechobee storage, the Lake Belt storage areas are in-ground storage reservoirs. As for the above ground reservoirs, the Lake Belt reservoirs are simulated as leveed systems identified by a hydrologic basin number assigned to appropriate grid cells. The land surface elevation is the grid cells within the reservoirs are lowered such that the maximum storage simulated by the model closely approximates the actual maximum storage. Since the reservoirs are in ground storage areas, the area of the Lake Belt reservoirs are represented by the grid system, i.e., multiples of four square miles.

Both reservoirs are proposed to have seepage barriers. For modeling purposes, seepage barriers are located at the boundaries of grid cells. Seepage barriers are identified in the model by specifying the appropriate boundary faces (east, west, north, or south) of an affected grid cell locations (column, row). By temporarily fixing the head on the neighboring grid cell across a seepage barrier to be identical to the head at a computational grid cell, a zero head gradient is established between the two grid cells. The solution for the groundwater flow equations will yield zero flow across the common boundary when the seepage barrier is proposed, but the final end of day heads at either grid cell will still respond to the head gradients established at the other boundary faces where no seepage barrier(s) exists. Flexibility exists in the model to implement seepage barriers in the wet season (June-October) or dry season (November-May) at any boundary face within the grid network, excluding boundary cells of the SFWMM domain.

## **5. Aquifer Storage and Recovery**

More than 300 wells will be built to store water 1,000 feet underground in the upper Floridan aquifer. The wells will be located around Lake Okeechobee, in Palm Beach County, and in the Caloosahatchee Basin. As much as 1.6 billion gallons a day may be pumped down the wells into underground storage zones. Since water does not evaporate when stored underground and less land is required for storage, aquifer storage and recovery has some advantages over surface storage.

The largest use of Aquifer Storage and Recovery (ASR) is located around the northern shores of Lake Okeechobee. This component includes a series of aquifer storage and recovery wells adjacent to Lake Okeechobee with a capacity of 1-billion gallons per day and associated pre- and

post- water quality treatment in Glades and Okeechobee Counties. The initial design assumes 200 wells, each with the capacity of 5 million gallons per day with 8 ultrafiltration water quality pre-treatment facilities and aeration for post-treatment. Based on information for existing aquifer storage and recovery facilities, it is assumed that recovery of aquifer-stored water would have no adverse effects on water quality conditions in Lake Okeechobee. In fact, some level of nutrient load reduction may occur as a result of aquifer storage, which would be a long-term benefit to in-lake water quality conditions. The level and extent of treatment and number of the aquifer storage and recovery wells may be modified based on findings from a proposed aquifer storage and recovery pilot project (U.S. Environmental Protection Agency, 1999).

The pilot project would also investigate changes to water chemistry resulting from aquifer storage and identify post-retrieval water quality treatment requirements, if any, necessary to implement aquifer storage and recovery facilities. Pilot studies will be conducted to investigate the proposed facilities, including water quality changes associated with aquifer storage and recovery.

The purpose of this feature is to: (1) provide additional regional storage while reducing both evaporation losses and the amount of land removed from current land use (e.g. agriculture) that would normally be associated with construction and operation of above-ground storage reservoirs; (2) increase Lake Okeechobee's water storage capability to better meet regional water supply demands for agriculture, Lower East Coast urban areas, and the Everglades; (3) manage a portion of regulatory releases from the Lake Okeechobee primarily to improve Everglades hydropatterns and to meet supplemental water supply demands of the Lower East Coast; (4) reduce harmful regulatory discharges to the St. Lucie and Caloosahatchee Estuaries; and (5) maintain and enhance the existing level of flood protection.

In the SFWMM several forms of ASR are simulated. One form is utility ASR where ground water is pumped down from the surficial aquifer to the deeper confined aquifer using municipal utilities as the source during the wet season and later retrieved by the municipal utilities to help meet urban needs during the dry season. This is simulated in the SFWMM by simply altering the municipal wellfield data file, which includes increasing pumpage from the surficial aquifer during the wet season and decreasing pumpage during the dry season for the affected wellfields, taking into account the capacity of the utility ASR, and the efficiency in retrieving the water from the utility ASR.

Other forms of ASR simulated are in association with excessive canal flow, local reservoirs, and/or Lake Okeechobee. Pumpage down to ASR is simulated as an additional outlet from the appropriate source. Water retrieved from ASR is routed to the appropriate destination. The efficiency of ASR retrieval is typically assumed to be 70%. The net accumulation of excess water injected into deep aquifer, known as the ASR bubble, is assumed to have no limit in size.

In all cases the retrieval capacity of ASR wells is assumed to be the same as the pump down (injection) capacity. The ASR bubble size, which is updated on a daily basis, can be a limiting factor in ASR retrieval during extended drought periods when there is little or no water left to retrieve.

## **6. Water Conservation Areas 3A and 3B Levee Seepage Management**

Because of large seepage losses from the WCAs and ENP to the east, seepage control is necessary for Everglades restoration and for the purposes of water supply or environmental enhancement. The extent of seepage control depends on the magnitude of the seepage losses, the purpose of the storage area or reservoir, and flood control considerations in nearby areas.

To reduce seepage from WCAs 3A and 3B to improve hydropatterns within the Conservation Areas this component allows higher water levels in the borrow canals and longer inundation durations within the marsh areas located immediately east of the WCAs. Additional levees, canals, pumps and water control structures will be constructed to maintain flood protection and separate seepage water from urban runoff currently backpumped from the urbanized basin to the east. Seepage collected in the protective levee borrow canals and from the marsh areas will be directed into a collection and conveyance system and directed south into the Central Lake Belt Storage Area or directly to Northeast Shark River Slough. During dry periods, Lake Okeechobee water supply deliveries will be routed through the same system as the stormwater is directed during storm events to keep lake deliveries separate from seepage due to the water quality constraints of the Everglades system.

In the SFWMM several options exist for simulating levee seepage and its management. These include; 1) allowing the seepage to occur with no diversion or management, 2) pump the seepage collected in the canal back to the source, 3) divert the seepage collected to another location that would benefit from the added seepage volumes, and 4) impose a barrier that would reduce or eliminate levee seepage losses (e.g. make levee seepage under protective levee(s) equal to zero). Management of levee seepage can be changed temporally at a grid cell location along a levee on a wet season-dry season basis and can vary spatially over the length of the levee as a function of grid cell location.

## **7. Decompartmentalization**

This component includes the construction of new water control structures and the modification or removal of levees, canals, and water control structures in Water Conservation Area 3A and B located in western Broward County. More than 240 miles of project canals and internal levees within the Everglades will be removed to reestablish the natural sheetflow of water through the Everglades.

The purpose of these features is to reestablish the ecological and hydrological connection between Water Conservation Areas 3A and 3B, the Everglades National Park, and Big Cypress National Preserve (Figure 7). Sheetflow obstructions will be removed with the backfilling of the Miami Canal and southern 7.5 miles of L-67A Borrow Canal, removal of the L-68A, L-67C, L-29, L-28, and L-28 Tieback Levees and Borrow Canals, and elevating of Tamiami Trail. Water supply deliveries to Miami-Dade County, previously made through the Miami Canal, will be rerouted through an expanded North New River Canal and an improved southern conveyance system. Eight passive weir structures to be located along the entire length of L-67A will also promote sheetflow from Water Conservation Area 3A to 3B during high flow conditions.

Decomartmentalization in the SFWMM is achieved by removing levees, backfilled canals and appropriate structures from the input data. Since levees are located at boundaries of neighboring grid cells where hydrologic basin numbers are different, removing the levees between water bodies in the model is done by making the hydrologic basin numbers the same for all cells within the neighboring water bodies.

Passive weirs are formed by degrading levees to a desired elevation over a certain distance at appropriate locations along the length of the levee. The weir crest elevation and length varies and are determined via trial-and-error to achieve the desired flow distribution. Discharge over these passive weir structures are simulated with a broad crested weir equation taking into account submergence. The discharge calculation is an integral part of the overland flow algorithm.

## **8. Lake Okeechobee Operations**

The Lake Okeechobee operational rules (regulation schedule) will be modified in order to take advantage of the additional storage facilities. Two additional zones will be added to the schedule (Figure 8). The first zone will trigger discharges to the “North of Lake Okeechobee” reservoir and the Everglades Agricultural Area reservoir. The second higher zone will trigger the Lake Okeechobee aquifer storage and recovery facilities to begin injecting water from the Lake. Climate-based forecasting will be used to guide management decisions regarding releases to the storage facilities. It is anticipated that all flood control releases through the existing C-43 and C-44 Canals will be eliminated with the exception of emergency Zone A (maximum flood control) discharges. Zone A levels are expected to be similar to the levels that occur in the current regulation schedule; however, the number of times that the Lake is above Zone A is expected to be dramatically reduced with these new operations.

A combination of existing data-driven features and new code was written to mimic the proposed operation in the SFWMM. For each daily time step, after delivering water supply needs and updating the Lake stage, the model determines the appropriate zone of the schedule and executes code to mimic the discharge operation. Discharge to North Storage and EAA storage generally occurs before ASR injection. If the Lake Okeechobee stage is above the Pulse release zone line (level 1), or is forecasted to be above the "Discharge to Storage" line within the next three months, then the Lake water is diverted to North Storage and EAA storage (when storage capacity exists). Similarly, if the Lake Okeechobee stage is above the Pulse release zone or forecasted to be above the "ASR Injection" line within three months, the Lake water is injected into ASR wells. Water is retrieved from North storage and ASR wells if the Lake stage is below, or forecasted to fall below the "ASR Recovery and North Storage Outflow" line within six months, for recovery during the dry season. During the wet season; however, water is retrieved if the Lake stage is below the "ASR Recovery and North Storage Outflow" line and if the climate-based inflow forecast is less than 1.5 million acre-ft for the next six months.

The use of climate forecasts in the simulation was achieved by pre-processing a time series of non-perfect six-month forecast of Lake inflow. The simulation checks the forecast daily, but the forecast is updated monthly. The forecast was produced using regional, global, and solar indicators which are emerging as useful tools for assisting operations, and for estimating inflows to Lake Okeechobee (Trimble, et al. 1998).

## 9. Rainfall-Driven Operations

Modifications to the operational schedules for Water Conservation Areas 2A, 2B, 3A, 3B, and the current rainfall-driven operations for Everglades National Park, will be made to implement rainfall-driven operations for all of these areas. These new operational rules are intended to improve the timing and spatial distribution of water depths in the Water Conservation Areas (WCAs) and Everglades National Park and to restore more natural hydropatterns.

The rain-driven operational concept is a basic shift from the current operational practice, which uses calendar-based regulation schedules for the WCAs. Regulation schedules, also referred to as flood-control schedules, typically specify the release rules for a WCA based on the water level at one or more key monitoring gages. Regulation schedules do not typically contain rules for importing water from an upstream source. The schedules also repeat every year and make no allowance for inter-annual variability. The rain-driven operational concept includes rules for importing water from upstream sources (e.g. the EAA Storage area, an upstream WCA, or Lake Okeechobee), and for exporting water from the WCAs in order to mimic a desired target stage hydrograph at key locations within the Everglades system. The target stage hydrographs mimic an estimate of the more natural (pre-drainage Everglades) water level response to rainfall.

The SFWMM simulated the rainfall-driven operations by using pre-processed target stage hydrographs at strategic monitoring locations, and via user-specified operational trigger levels. The target stage hydrographs were computed using the water depth hydrographs from the NSM, but adjusted for the current system topography. Modifications to the target stage hydrographs (e.g., truncating peaks or shifting the entire series downward) were made if recommended by the study team ecologists.

The term "trigger level" means the water level used to trigger action at an upstream or downstream control structure. Trigger levels are related to the target stage hydrographs by simple offsets which typically range less than  $\pm 1.0$  ft. There is usually one trigger level for the import rules; and two trigger levels associated with the exportation of water. The two export trigger levels define two release zones. The lower zone is a conditional release zone; so releases are made only if the downstream area has a "need". The upper zone is an unconditional release, or flood control, release zone; so releases are made in this zone even if the downstream area doesn't "need" the water. The trigger levels were adjusted during the modeling process via trial-and-error in order to maximize the matching of the simulated hydropatterns to the natural (pre-drainage) hydropatterns.

## **D. RESULTS**

The simulated performance of the Restudy alternative plans was analyzed through the use of over 900 hydrologic performance measures and indicators. In this section the performance of the Restudy plan recommended for the management of south Florida's water resources through 2050 (also referred to as the Future Condition) is compared with that of the Current Condition using selected performance measures and indicators. Discussion of the results is organized by the major geographic regions of southeastern Florida (Figure 2a).

### **1. Lake Okeechobee**

Lake Okeechobee is the second-largest freshwater lake lying wholly within the boundaries of the continental U.S., and is considered the liquid heart of southeastern Florida's water management system. It is managed for multiple purposes which currently include flood control, agricultural water supply for the surrounding lake service area, and during very dry periods it is used to deliver water to the canal systems of the lower east coast to prevent saltwater intrusion. Water levels are also managed to benefit the ecological health of the Lake itself, particularly the western portions of the Lake (littoral zone) which provide habitat to a variety of fish and bird species.

Several measures of performance were developed to estimate benefits and impacts to the health of the Lake that may occur from each alternative plan. One such performance measure defined undesirable lake stage events as follows:

1. Number of extreme low lake stages (<11 ft),
2. Prolonged moderate low lake stages (number of events <12 ft for >12 months),
3. Number of extreme high lake stages (>17 ft),
4. Prolonged moderate high lake stages (number of events >15 ft for >12 months), and
5. Spring recession patterns (number of years where from January - March lake stages decline from near 15 ft to 12 ft without stage reversals >0.5 ft)

Prolonged low lake levels reduce areas of the littoral zone available for wildlife habitat and promote exotic plant expansion. High lake levels can result in wind and wave damage to shoreline plant communities and limit light penetration to the lake bottom. Some variation within an intermediate lake stage range has great benefits. In particular, a spring recession of lake levels from near 15 feet to 12 feet NGVD has been shown to favor nesting birds and other wildlife in the marsh, and also facilitate the growth of submerged plant communities, which serve as habitat for commercially and recreationally important fish.

Table 1 summarizes the number of undesirable extreme lake stage events determined from simulated lake stage hydrographs. The future with the Restudy plan improves on the current condition, but doesn't meet the desired target. However, the recommended plan shows a significant improvement as compared with the future condition without the Restudy plan.

Table 1. Number of Undesirable Lake Okeechobee Extreme Stage Events

Criteria	Target*	Current System	Future System W/out Plan	Future System With Plan
Too High	1	3	2	2
Too Low	1	3	10	2
Total	2	6	12	4

\* target based on biologically acceptable frequency over the 31-yr simulation period

## 2. Estuaries

Two major estuaries, the Caloosahatchee and St. Lucie (Figure 2a) have traditionally received flood control discharges from Lake Okeechobee. These inflows from the lake as well as inflows from local basin drainage have frequently upset the delicate estuarine salinity balance and caused ecological damage to bed-grasses, oysters and other important parts of these estuarine ecosystems. Performance measures for the estuaries are related to counting the number of discharge events that exceed desired maximum salinity thresholds, or fall below desired minimum salinity thresholds.

Table 2 summarizes the number of months that fall outside the desired range of the salinity envelope criteria for the estuaries. The storage features of the plan serve to capture much of the excess Lake and local basin water, thereby significantly reducing the number of high flow exceedences. Similarly, the new storage areas have supplies that are delivered during drier periods which significantly reduce the number of low flow criteria exceedences.

Table 2. Number of months with ecologically damaging excessively low or high flows.

Estuary	Salinity Envelope Criteria	Target*	Current	Future
St. Lucie	Low (< 350 cfs)	50	154	51
	High (14 day avg > 1600 cfs)	13	127 (40)**	33(2)**
Caloosahatchee	Low (< 300 cfs)	50	107	36
	High (> 2800 cfs)	22	69 (23)**	11(1)**

\* target based on biologically acceptable frequency over the 31-yr simulation period

\*\* numbers in parenthesis are the events due to Lake Okeechobee discharges

## 3. Lake Okeechobee Service Area

The Lake Okeechobee Service Area (LOSA) includes the half-million acres of sugar cane farms of the Everglades Agricultural Area (EAA), and the predominately citrus grove regions of the Caloosahatchee and St. Lucie River basins (Figure 2a). Other smaller agricultural and urban areas surrounding the lake are also part of the LOSA. Most of the LOSA depends on Lake Okeechobee as it's only source of supplemental irrigation.

Performance measures were developed to evaluate the frequency, duration and severity of water supply cutback events in the LOSA. The number of years with water restrictions exceeding a selected cutback volume threshold was used as the primary performance measure for the LOSA. The established performance target was for cutbacks to occur in no more than three years over the 31-yr simulation.

Table 3 summarizes the performance of the Restudy (Future) plan and compares it with the performance of the current condition. Also shown in Table 3 is the performance of the Lower East Coast Service Areas which is discussed in a later section. The Restudy plan significantly improves water supply performance for the LOSA, but falls short of the target performance of no more than three years of shortages during the 31-year simulation.

Table 3. Frequency of water restrictions (number of years in 31 year period)

Service Area	Current	Future
Lake Okeechobee Service Area	11	5
Northern Palm Beach County	11	2
LEC service area 1 – Palm Beach County	13	2
LEC service area 2 – Broward County	23	5
LEC service area 3 – Miami-Dade County	9	4

#### 4. Everglades Region

The Everglades region includes the remnant Everglades; namely the Water Conservation Areas (WCAs) and Everglades National Park (ENP) (Figure 2a). Many measures of performance were used to assess the degree to which the alternative plans met targets. In most cases the targets were based on the goal to reproduce the hydrologic characteristics of the pre-drainage system. The AET recognized that achieving hydrologic restoration does not guarantee ecological restoration; however the team assumed that reconstructing the natural or pre-drained hydrologic characteristics will provide maximum opportunity for recovery of the remaining Everglades landscape patterns and natural wildlife.

The hydrologic characteristics that were most important to the AET were related to the duration of time an area was inundated (hydroperiod), and the depth of water above or below land surface elevation. Overland flow patterns and flow volumes were also considered important, but not as much as the timing and spatial distribution of water depths.

##### *Ponding Depth and Hydroperiod Patterns*

Figure 9 illustrates the average surface water depths and flow patterns for the pre-drainage condition, the current system, and the future system with the recommended Restudy plan. Figure 10 compares the same three simulations but uses the mean annual hydroperiod (days of inundation per year) as an indicator of performance. These maps are useful in comparing the similarity of spatial patterns for average temporal conditions.

The current system is characterized by a significantly reduced spatial extent of surface water relative to the predrained condition. The current system also exhibits shallower water depths and shorter hydroperiods in northern portions of the WCAs, and deeper water in the southern parts of the WCAs. The degree to which water flowed continuously through the Everglades has also been reduced due, in part, to the WCA impoundments. This is particularly true in northeastern Everglades National Park. The future (with plan) system generally shifts the hydropatterns in the remaining Everglades to more closely resemble those of the predrained condition.

### *Hydroperiod Matches*

Table 4 quantifies the proportion of the remaining Everglades that is estimated to match the mean annual hydroperiod of the pre-drainage system. The Restudy plan is estimated to improve more than 290,000 acres of Everglades wetlands to exhibit more natural hydroperiods.

Table 4. Percentage of area with mean hydroperiods within 30 days of NSM hydroperiods

Portion of the Remaining Everglades	Current	Future
Water conservation Areas (840 thousand acres)	62 %	74 %
Eastern Everglades National Park (486 thousand acres)	56 %	95 %

### *Mean Annual Flow Volumes and Seasonality*

Although not considered by the AET to be the most important measure of performance for the Everglades, the volume and timing of surface water flow to the Everglades was examined to assess performance of the alternative plans. Table 5 summarizes the simulated net inflows to ENP and also expresses them as a percentage of the corresponding NSM flows.

Table 5. ENP Overland Flows in 1000 ac-ft/year and as a Percentage of NSM flows.

	Target (NSM)	Current	Future
Total Net Inflow to ENP	1637	862 (53%)	1312 (80%)
Outflow via Shark Slough	1566	706 (45%)	1110 (71%)

Figure 11 compares the seasonal distribution of overland flow across selected transects through the remaining Everglades. The overland flow volumes are expressed as a fraction of the corresponding NSM volumes. From Table 5 and Figure 11 it can be concluded that in the future (205) with the Restudy plan, there should be a significant increase in the volume of overland flow through the Everglades; and the seasonal timing will become much more like that of the pre-drainage system.

## **5. Lower East Coast Service Area**

The developed portions of southeastern Florida, east of the WCAs and ENP (Figure 2a), comprise the Lower East Coast Service Area (LECSA). Population growth during the next 50 years in Palm Beach, Broward and Miami-Dade Counties is expected to increase demands for potable water by more than 50%, from current use of about 900,000 ac-ft/yr to 1,400,000 ac-ft/yr. Although the vast majority of this water is supplied from the prolific Biscayne Aquifer, the LECSA depends on the Everglades for some passive recharge of the aquifer. Also, during dry periods, surface water is delivered from the Everglades WCAs or Lake Okeechobee to the primary canals in the LECSA in an effort to recharge the aquifer and prevent saltwater intrusion.

During times of drought, the South Florida Water Management District will issue short-term water use restrictions, or cutbacks, if local groundwater levels are below prescribed minimum levels. The LECSA can also experience water use restrictions if levels in Lake Okeechobee are low enough to restrict water use in the LOSA.

Performance of alternative Restudy plans was evaluated primarily with a measure that quantified a public water supply planning goal (target) of a 1-in-10 year level of service. The target is quantified as no more than three years during the 31-year simulation that have cutbacks longer

than seven months in duration. From Table 3 the performance of the Restudy Plan is seen to significantly improve over that of the current condition. The target of no more than 3 years in the 31-year simulation with cutbacks was met for Palm Beach County, but was slightly short of the target (by 1-2 additional years) for Broward and Miami-Dade Counties.

## 6. Summary of Results

The AET evaluated performance of all the Restudy alternative plans using a variety of performance measures and several different evaluation methodologies ranging from complex methods to simple ranking, grading, and color coding. The simple methods were very useful for conveying a general qualitative understanding of the level of improvement afforded by the recommended plan.

Table 6 summarizes the color rating of the recommended plan and the current without project condition. Each color provides two kinds of information: (a) a prediction of how likely the recovery and long-term sustainability objectives defined by the performance measure(s) will be achieved; and (b) a recommended priority for further improvement in the design and operation of the alternative plan. Green means that the alternative plan is likely to recover and sustain the ecological or water supply objective described by the performance measures. Yellow means that achievement of the long-term objectives is marginal or uncertain, and that improvement in the plan is a moderate priority. Red means that the recovery and long-term sustainability of the objectives are unlikely, and that the current plan requires improvement to meet these targets.

Table 6. Summary report card illustrating performance by simple color coding methodology.

Subregion	Current Condition (w/out Restudy plan)	Future Condition (with recommended plan)
Lake Okeechobee	Y	G
St Lucie Estuary	R	G
Caloosahatchee Estuary	R	G
Lake Worth Lagoon	Y	Y
Loxahatchee NWR	Y	G
Holeyland and Rotenberger	Y	G
WCA 2A	R	G/Y
WCA 2B	R	R
Northwestern WCA 3A	R	G
Northeastern WCA 3A	R	Y
Eastern WCA 3A	R	Y
Central & Southern WCA 3A	R	G/Y
WCA 3B	R	Y
Shark River Slough	R	G
Rockland Marl Marsh	R	Y
Biscayne Bay	Y	G
Florida Bay	R	G
Pennsuco	Y	G
C-111 Basin	Y	G

South Big Cypress	Y	G
SE Big Cypress	Y	G
Connectivity	Y	G
Sheet Flow	R	G
Fragmentation	R	G
Lake Okee. Service Area	R	G
Urban lower East Coast	R	G

In nearly all of the subregions the recommended Restudy plan is expected to improve performance. Twenty-four of the twenty-six subregions scored a green rating; and only two subregions did not improve.

## E. SUMMARY AND CONCLUSIONS

In the C&SF Project Comprehensive Review Study, 60 water resources management components were incorporated into the South Florida Water Management Model which was used to simulate several different alternative plans for the management of south Florida's water resources through 2050.

The Restudy was a success due, in part, to the utility of the South Florida Water Management Model. The SFWMM is currently the best available tool to address regional water management issues in South Florida (Loucks, et al, 1998). The SFWMM is unique because it integrates surface water, groundwater, and water management policies for south Florida's extensive water management system. The SFWMM was the key integrator and tester of current and proposed structural and operational components for the Restudy.

From the SFWMM simulations, the projected performance of complex alternative plans was analyzed through a highly structured evaluation process which provided useful feedback for subsequent alternative designs and also led to selection of the preferred plan.

The recommended Restudy plan is expected to produce major improvements toward the hydrologic restoration of the remaining Everglades, Lake Okeechobee and the St. Lucie and Caloosahatchee Estuaries. The plan is projected to be successful in shifting the hydropatterns in the remaining Everglades to more closely resemble those of the predrained condition. And the plan also provides water supply benefits to help meet the needs of an expected 50% increase in population of the lower east coast of Florida. Increased flexibility is also provided by the plan in that its components can be operated to achieve a broad range of benefits.

Although the regional-scale SFWMM was successful in shaping the comprehensive plan, more detailed studies are needed to further design the plan components prior to construction. Regional modeling with the SFWMM will continue through the implementation process to test the evolution of the system to help assure that system wide benefits are maximized.

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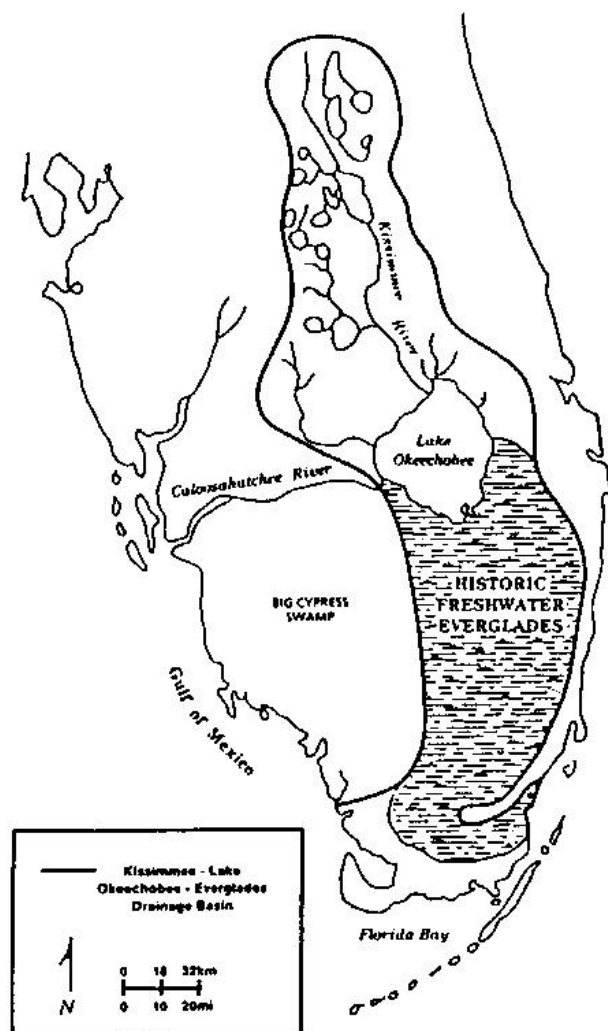


Figure 1a. Location of the pre-development Kissimmee-Okeechobee-Everglades watershed in south Florida (source: Maltby and Dugan, 1994).

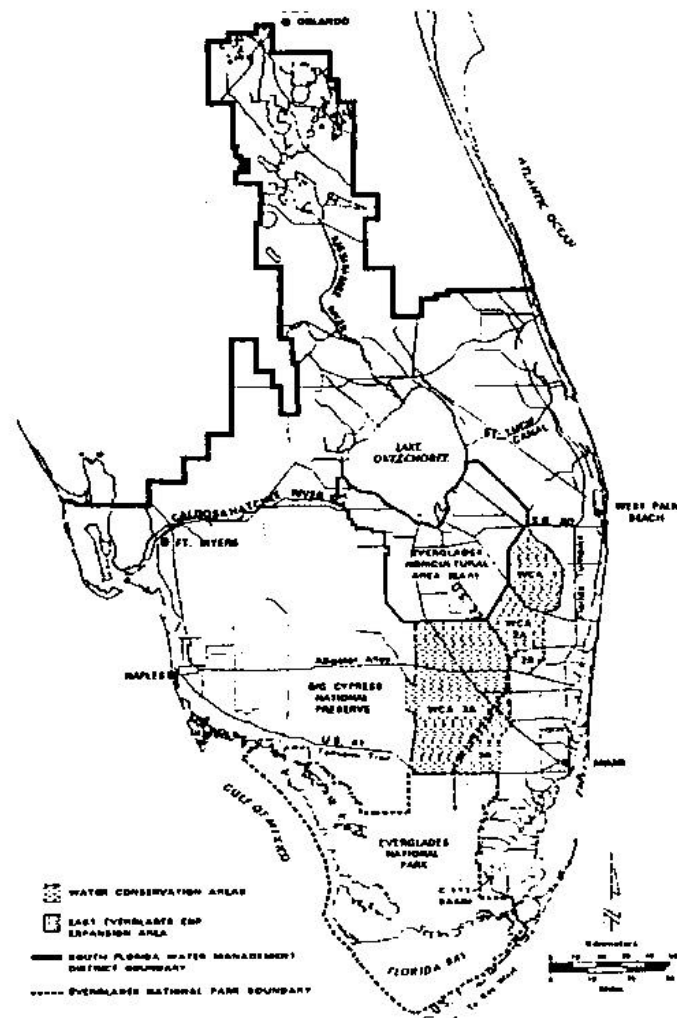


Figure 1b. Location of the present-day features within the South Florida Water Management District (source: Maltby and Dugan, 1994).

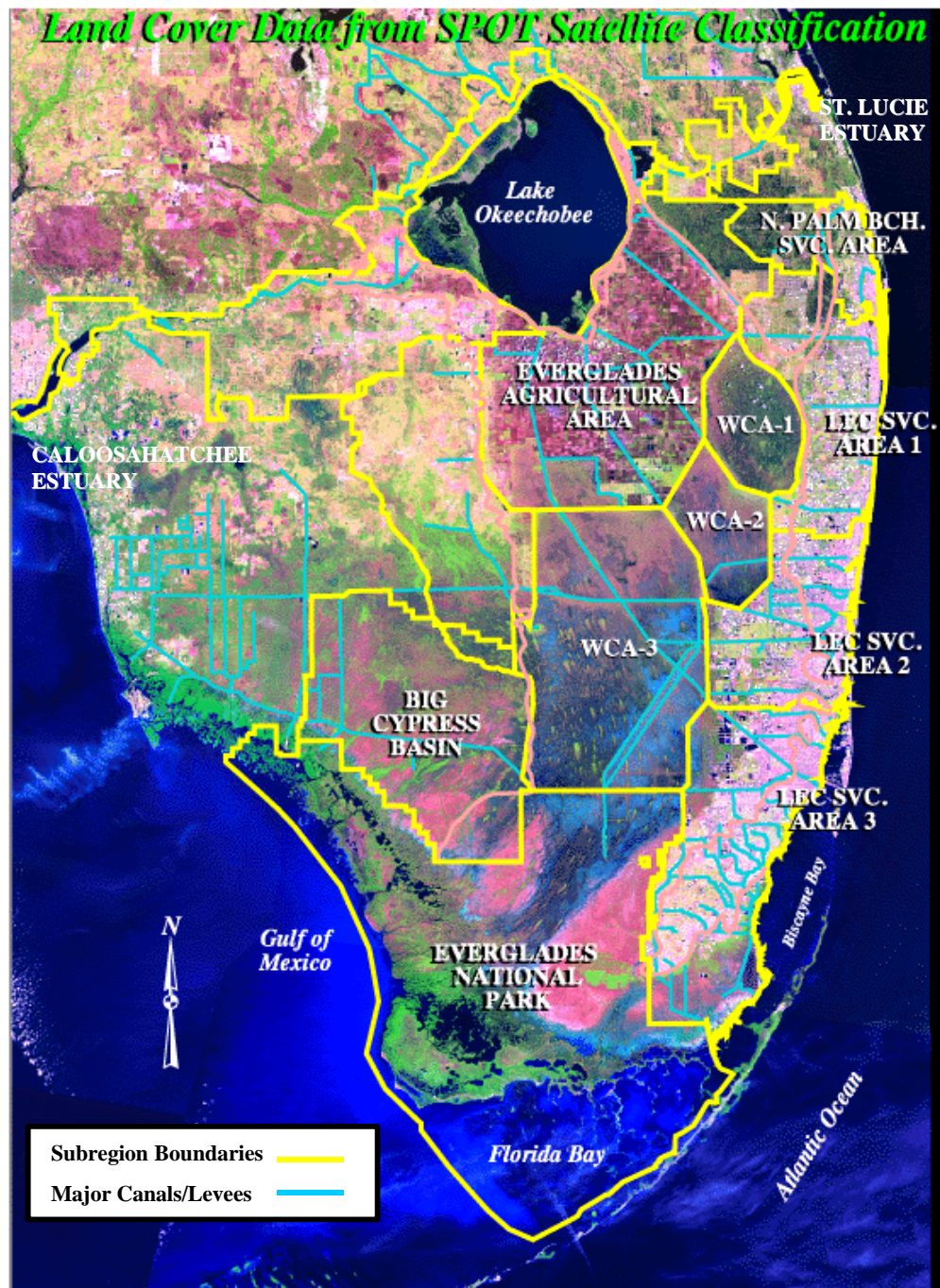


Figure 2a. Major geographic subregions of south Florida.

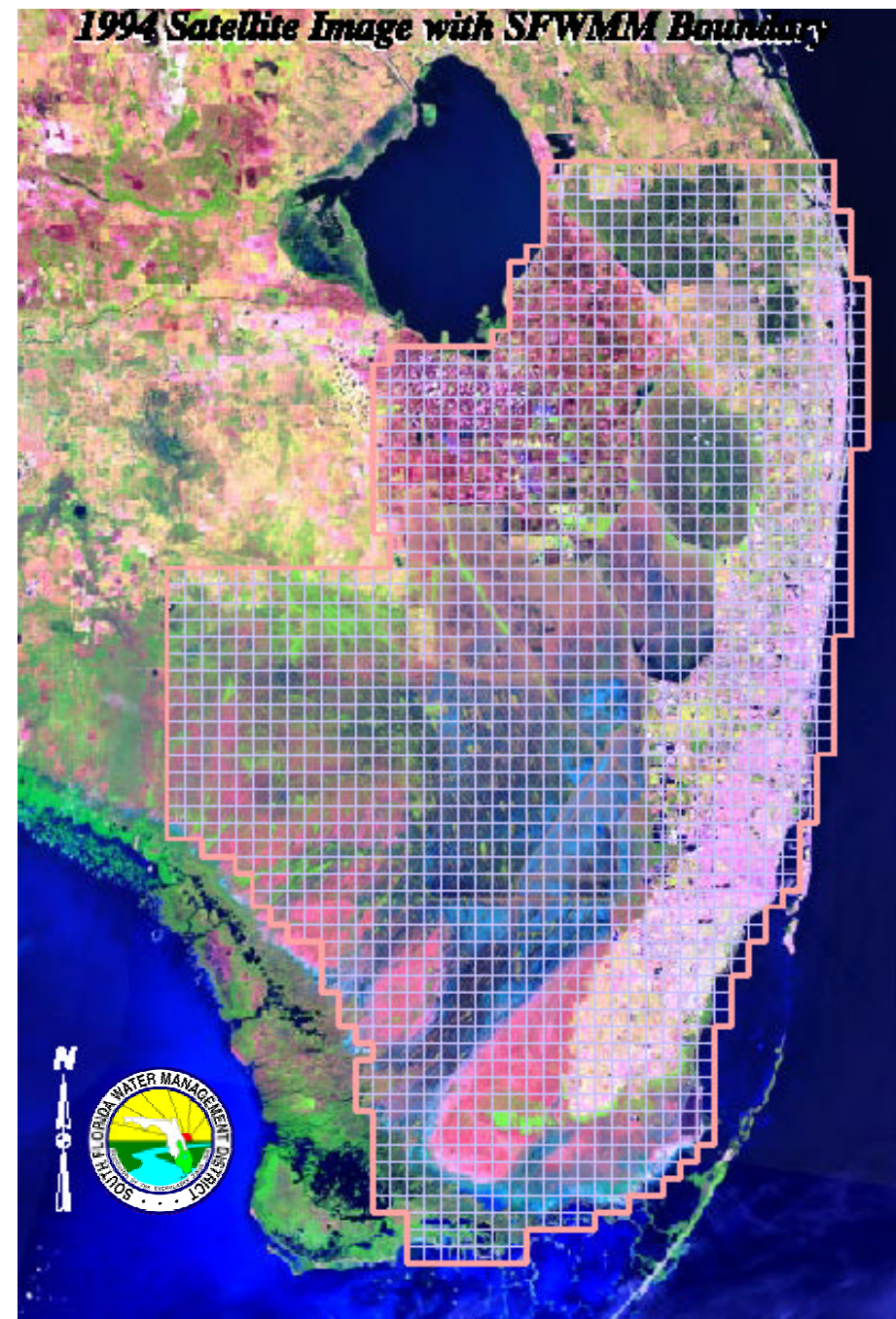


Figure 2b. South Florida Water Management Model domain showing 2mile x 2mile grid cells.

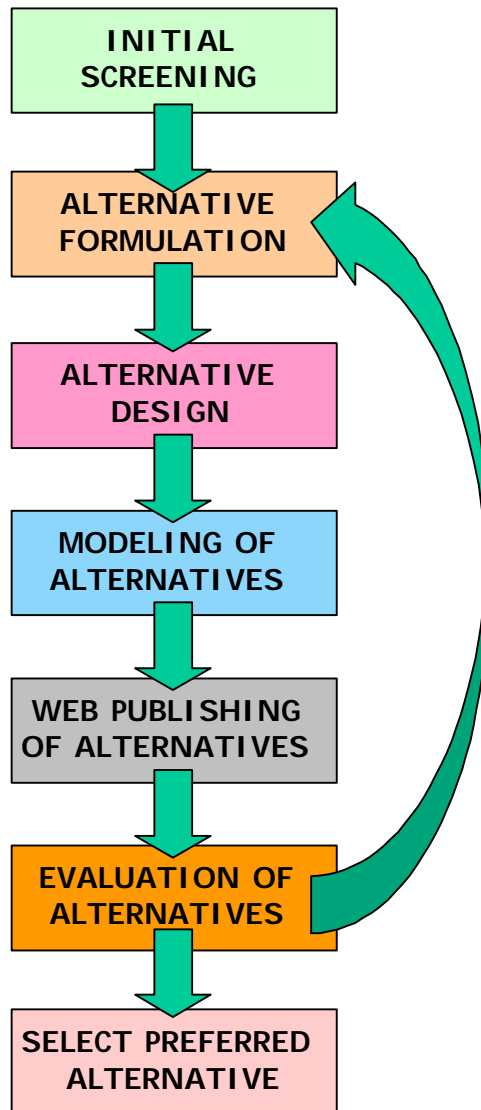


Figure 3. Restudy planning process for alternative development, modeling, web publishing and evaluation

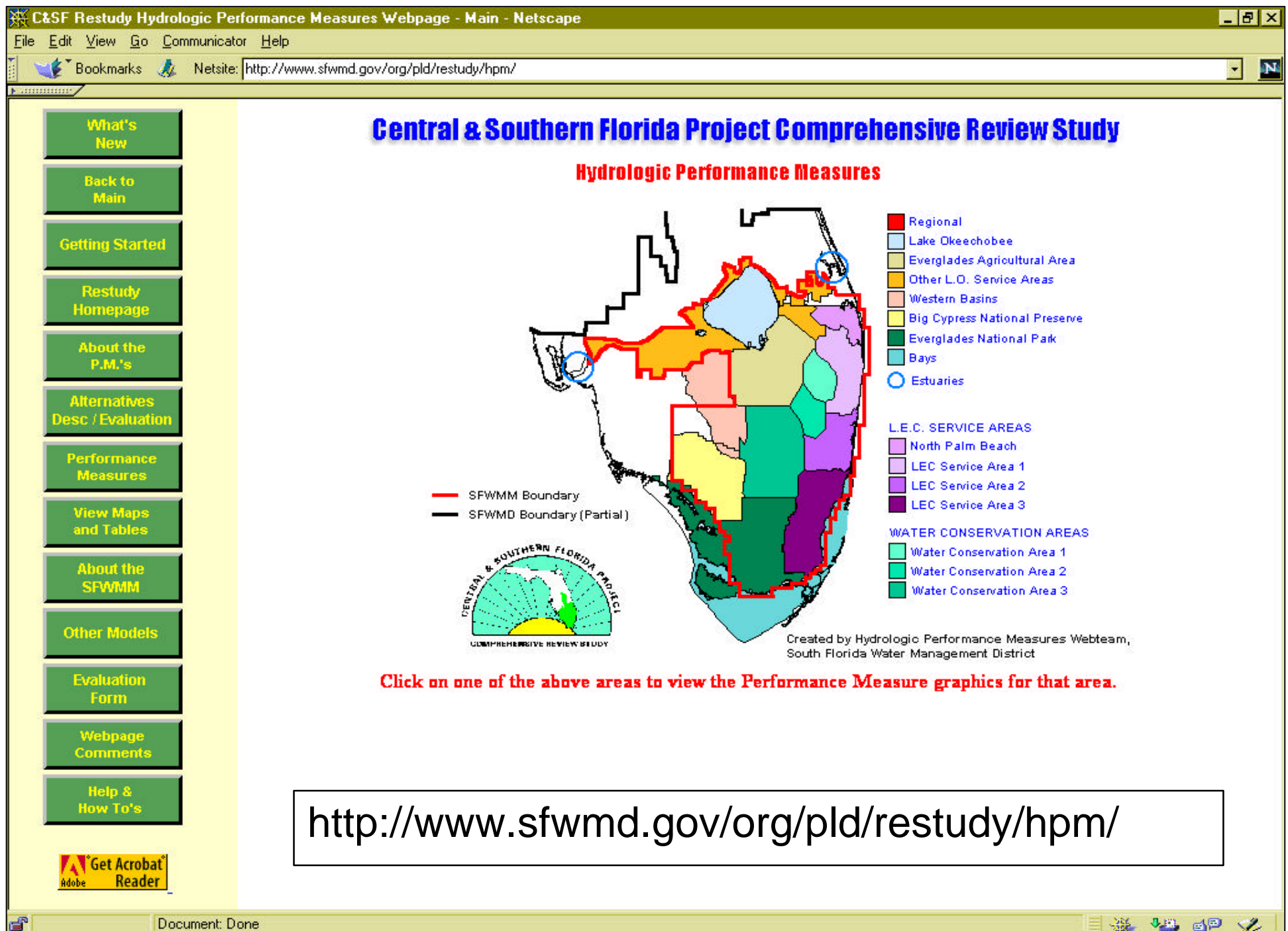
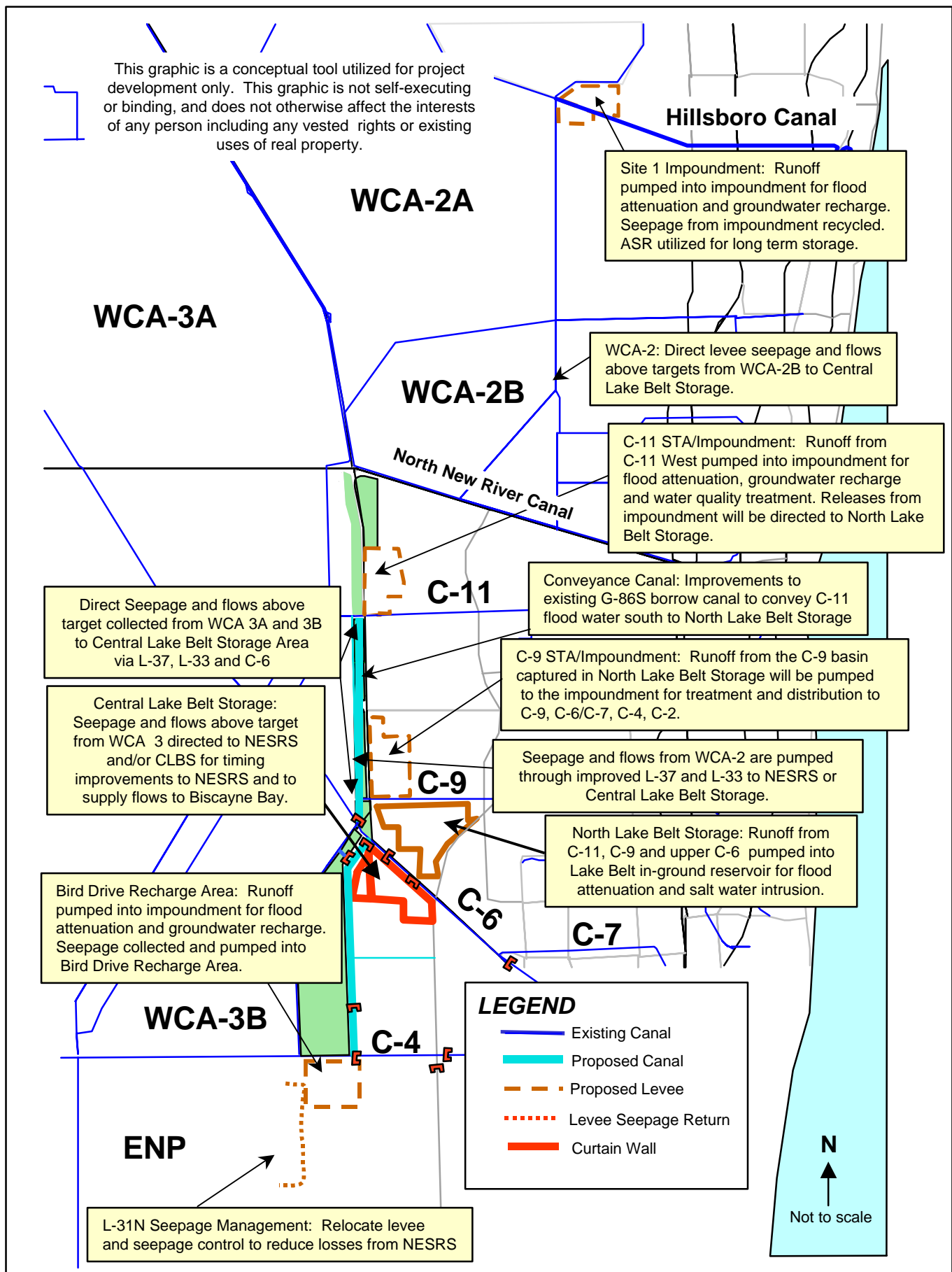
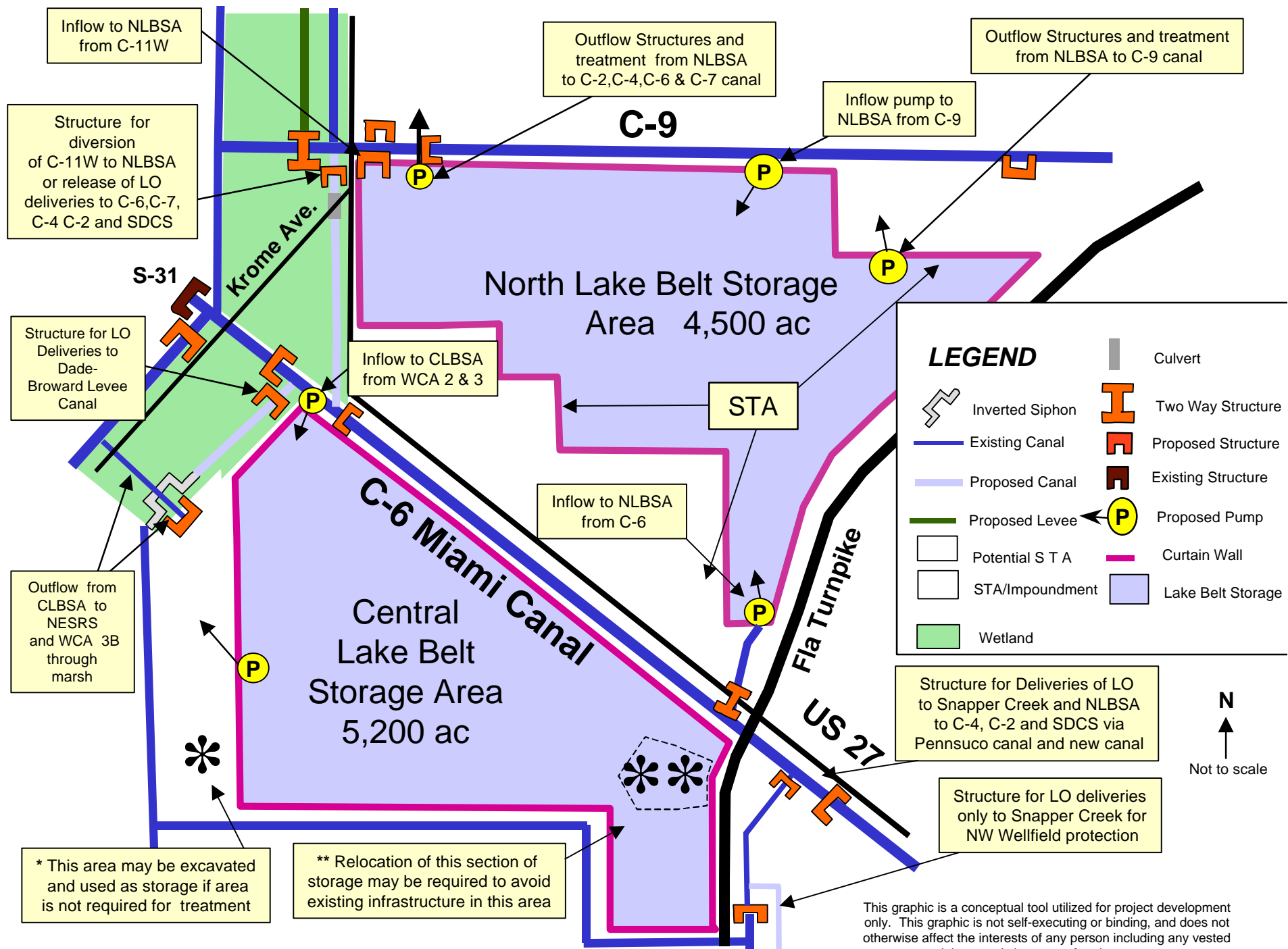


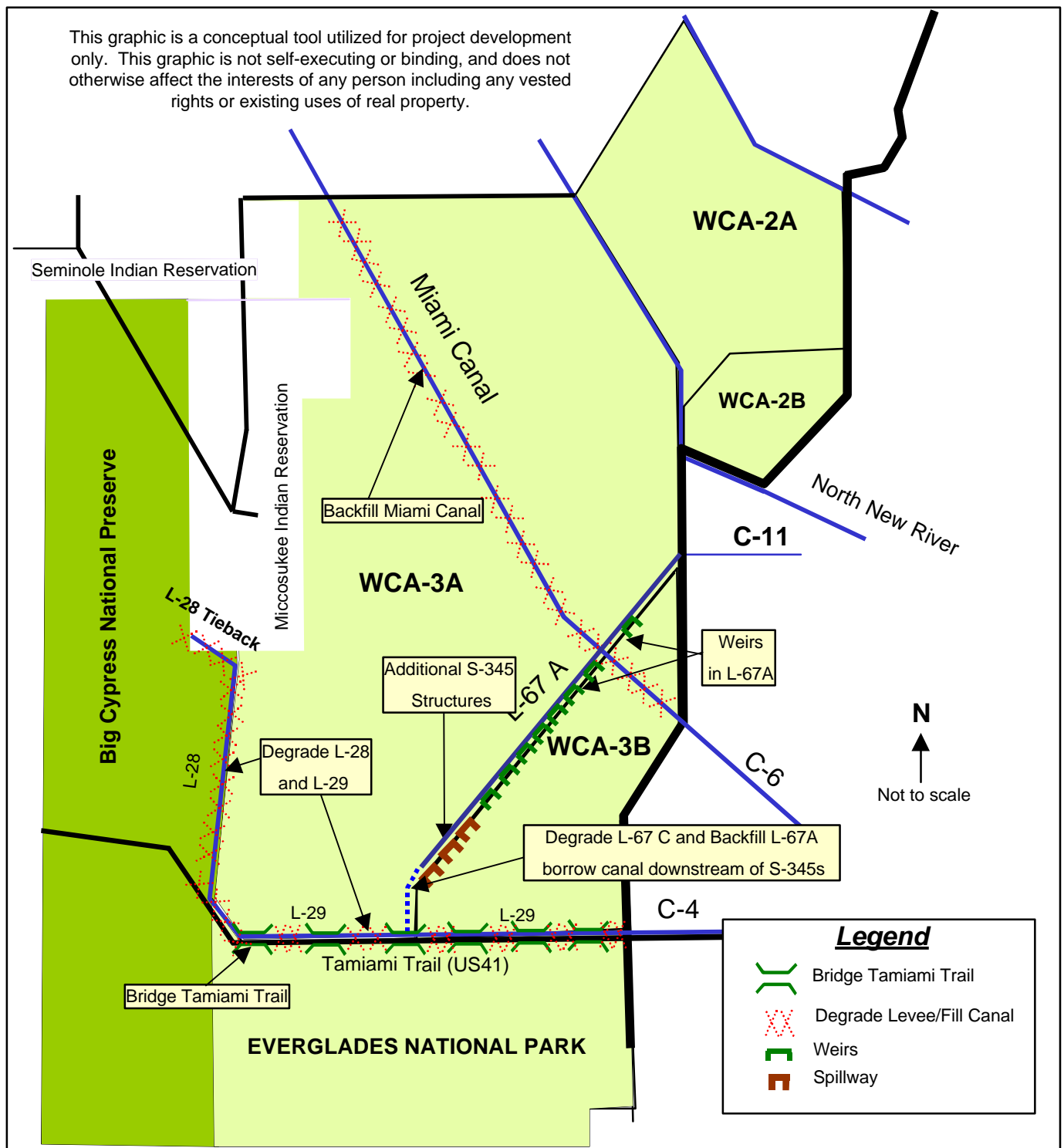
Figure 4. Hydrologic Performance Measures webpage for the Restudy.



**Figure 5. Features of the Water Preserve Area Component of the Restudy Plan.**



**Figure 6. Features of the Lake Belt Storage Areas proposed by the Restudy Plan.**



**Figure 7. Features of the Decartmentalization Component of the Restudy Plan.**

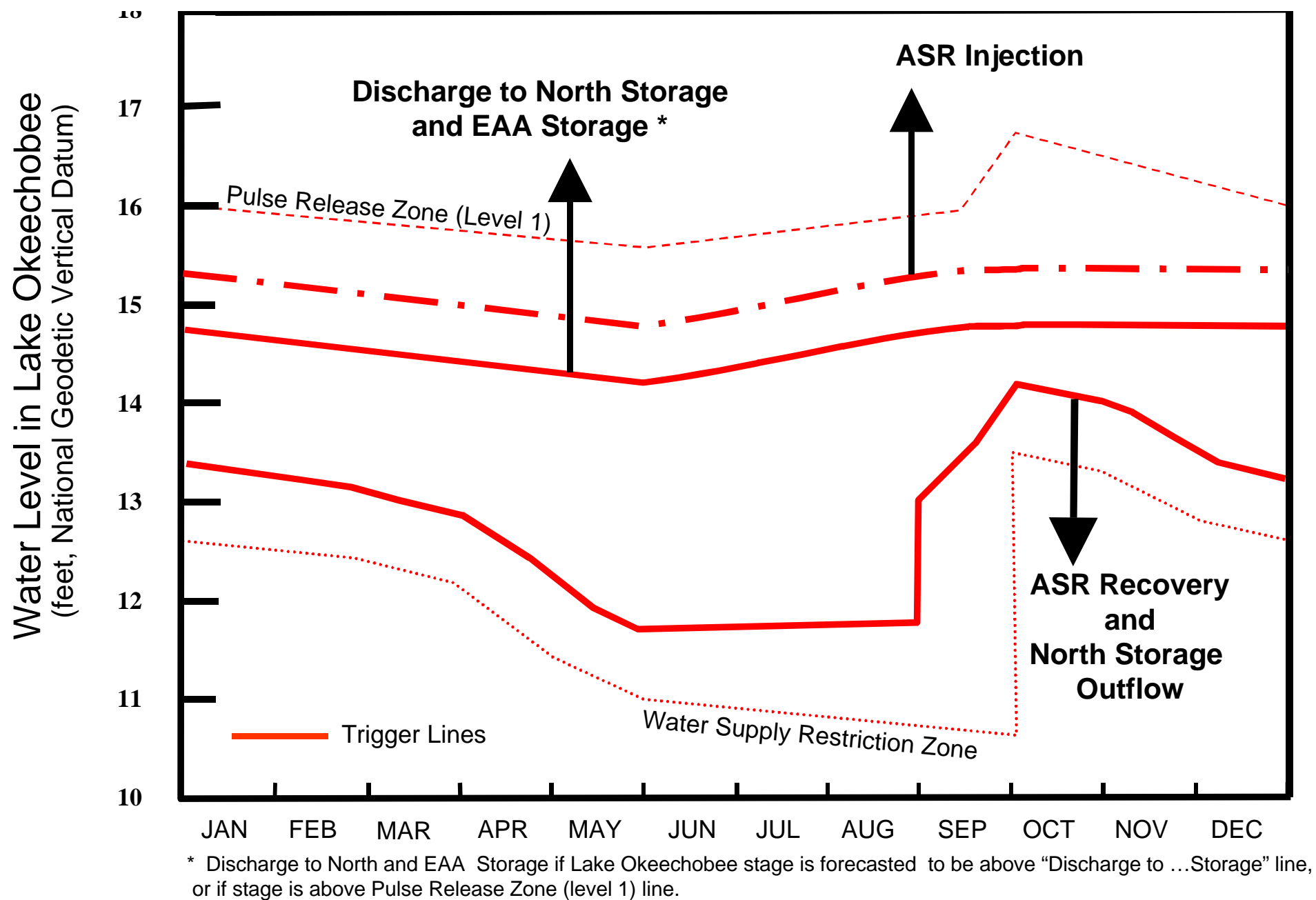
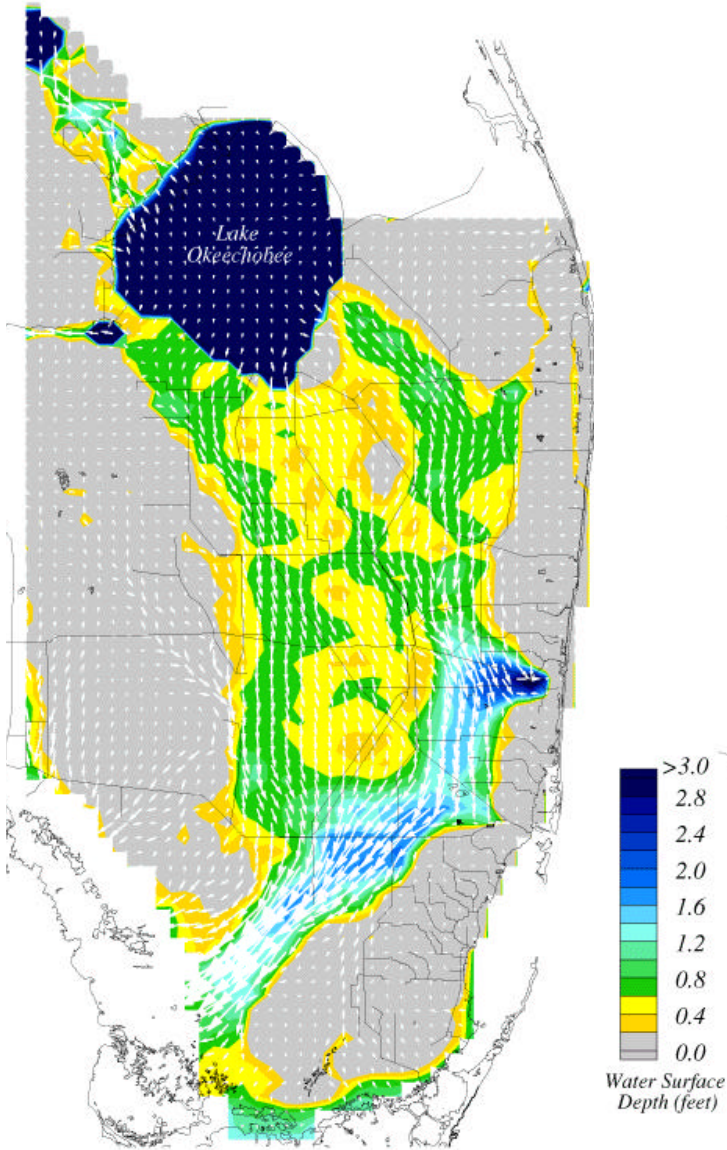


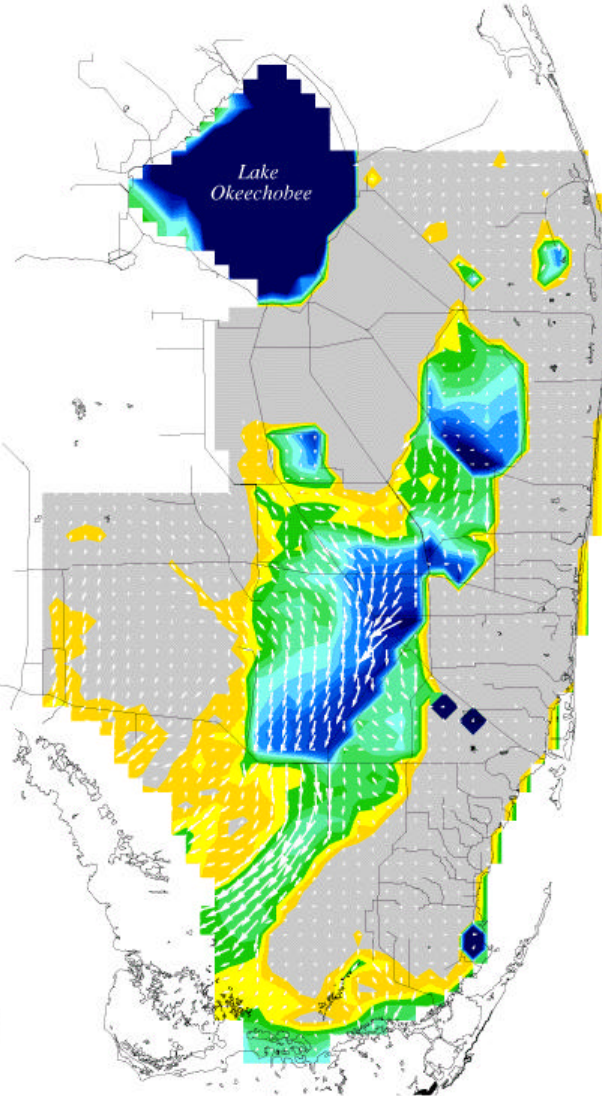
Figure 8. Operation Criteria for Lake Okeechobee and Surrounding Storage Components

NSM V.4.5 Surface Flows and Ponding



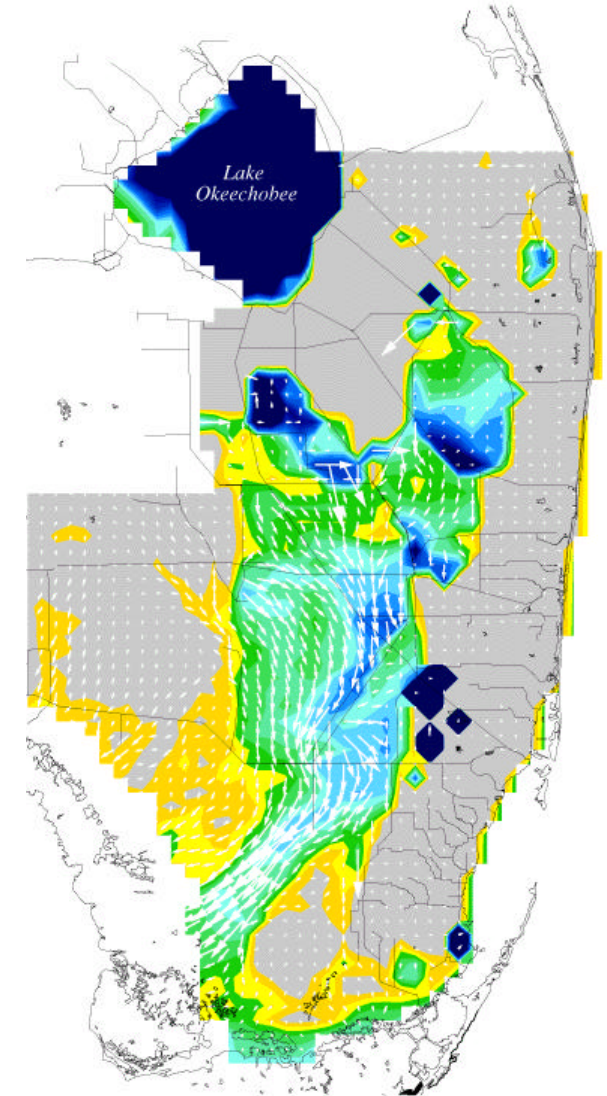
**PRE-DRAINAGE SYSTEM  
(CIRCA 1850)**

SFWMM Surface Flows and Ponding (1995 Base)



**CURRENT SYSTEM  
(1995)**

SFWMM Surface Flows and Ponding (Alt. D13R)



**FUTURE SYSTEM (2050)  
WITH RECOMMENDED PLAN**

Figure 9. Mean annual simulated surface water ponding depths and overland flows.

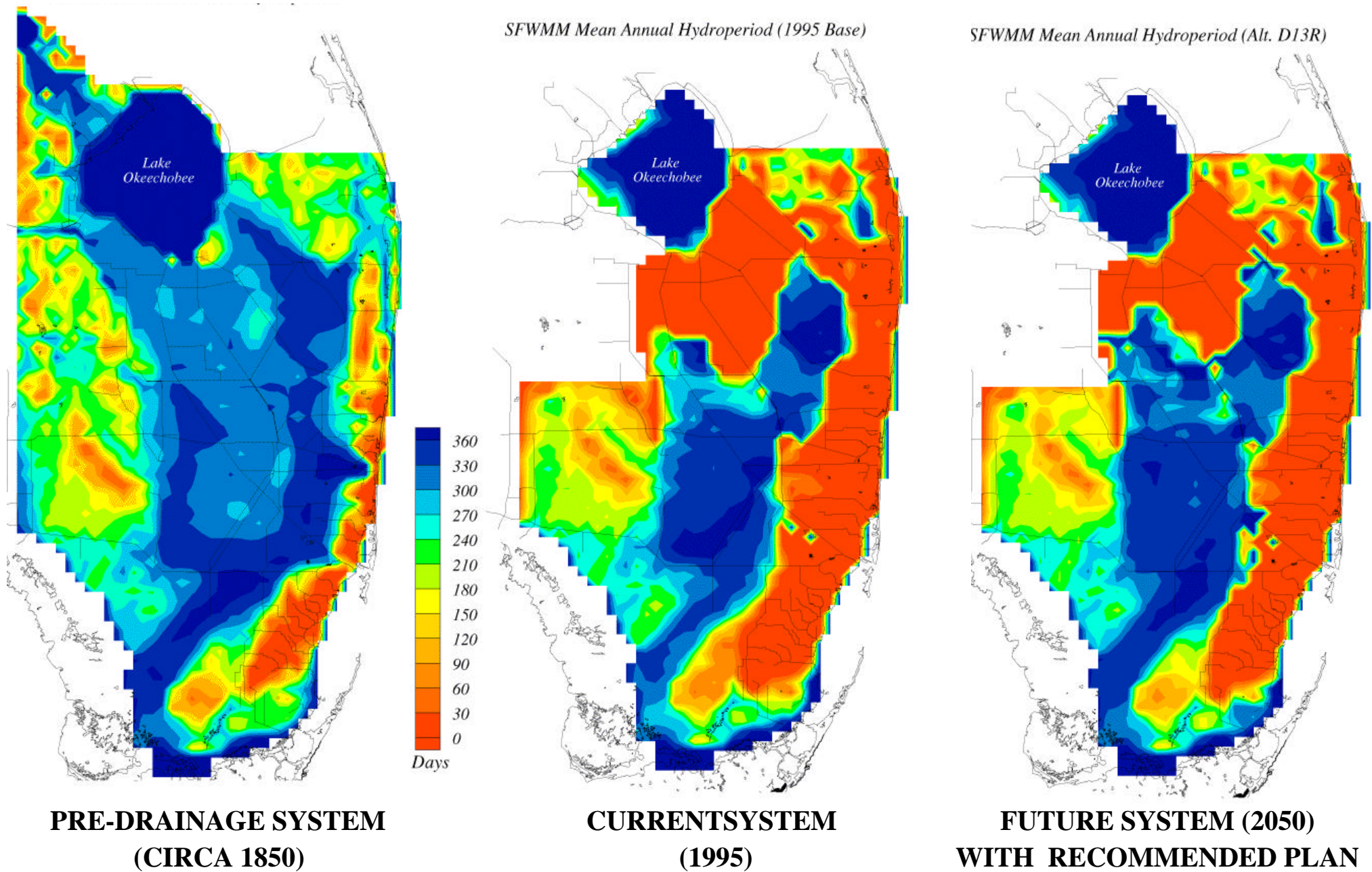


Figure 10. Mean annual simulated duration of inundation (hydroperiod).

## Seasonal Distribution of Flows Across Selected Transects

- WCA-3A North
- Tamiami Trail
- Whitewater Bay/Florida Bay

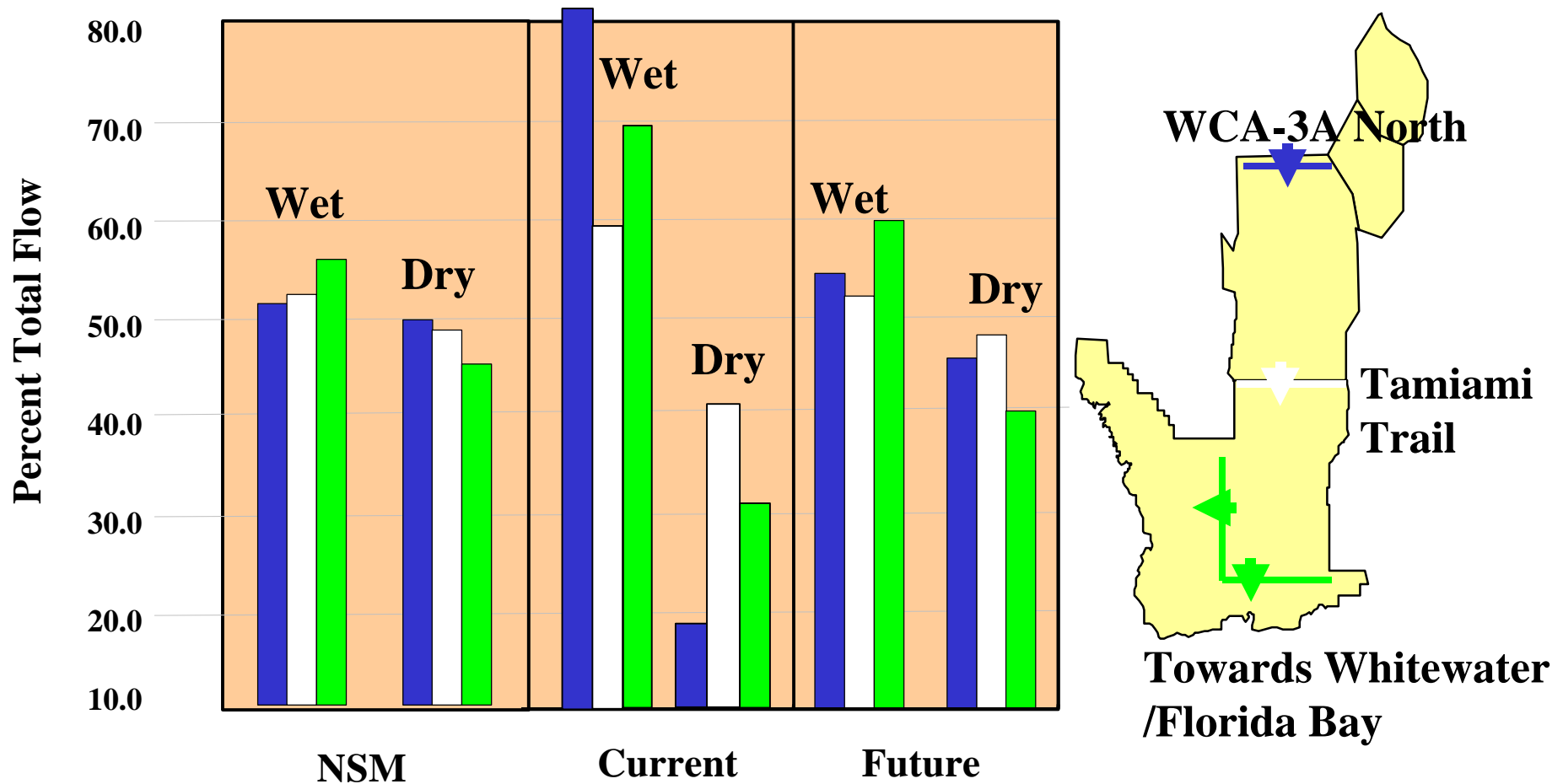


Figure 11. Seasonal distribution of overland flow across selected Everglades transects.